2.3 CARBOHYDRATES

Carbohydrates are the compounds of carbon, hydrogen and oxygen. Literally word carbohydrate means “hydrates of carbon” i.e., a carbon associated with water. Chemically carbohydrates are:

Carbohydrates The word (carbo- = “carbon”; hydrate = “water”)

Carbohydrates are organic compounds composed of elements carbon, hydrogen and oxygen.

They are hydrates of carbon.

Carbon + H_2O

C + H_2O ⟶ CH_2O

Empirical formula: CH_2O

The name carbohydrate means "watered carbon" or carbon with attached water molecules.

Empirical formula is a chemical formula showing the simplest ratio of elements in a compound rather than the total number of atoms in the molecule.

CH_2O

A molecular formula is a formula that represents the actual number of each atom in a compound. Whereas CH_2O is the empirical formula for glucose, $C_6H_{12}O_6$ is the molecular formula.

$C_6H_{12}O_6$

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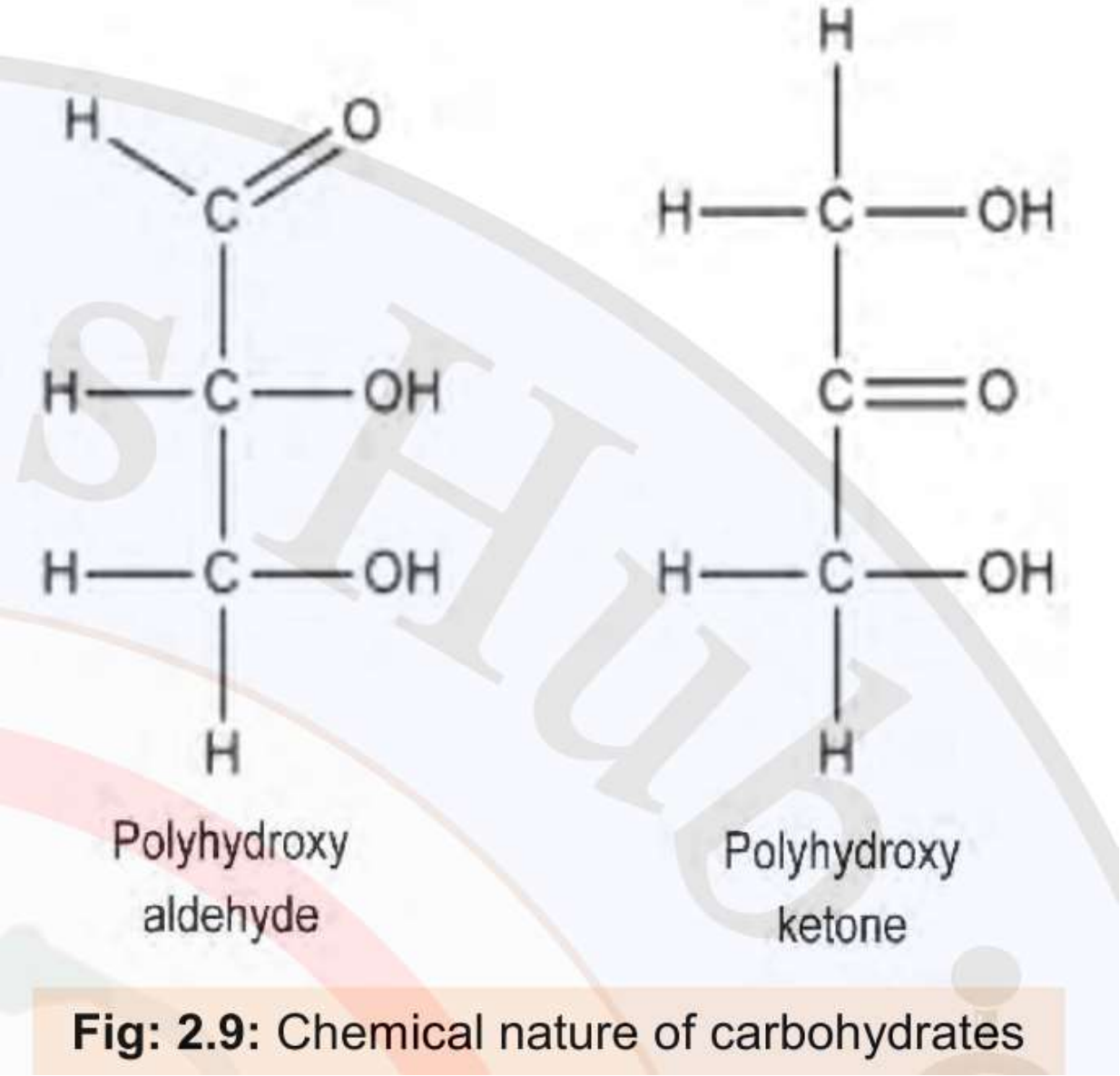

Fig: 2.9: Chemical nature of carbohydrates

Polyhydroxy aldehydes or ketones are molecules with more than one hydroxyl group (–OH), and a carbonyl group (C=O) either at the terminal carbon atom (aldose) or at the second carbon atom (ketose) are called carbohydrates.

2.3.1 Classification of Carbohydrates

Carbohydrates are commonly known as **sugars** or **saccharides** because more familiar carbohydrates have sweet taste. Classification of carbohydrates is based upon number of saccharide units. Carbohydrates are generally classified into three group i.e., monosaccharides, oligosaccharides and polysaccharides.

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Table: 2.2: Comparison of characteristics of carbohydrates

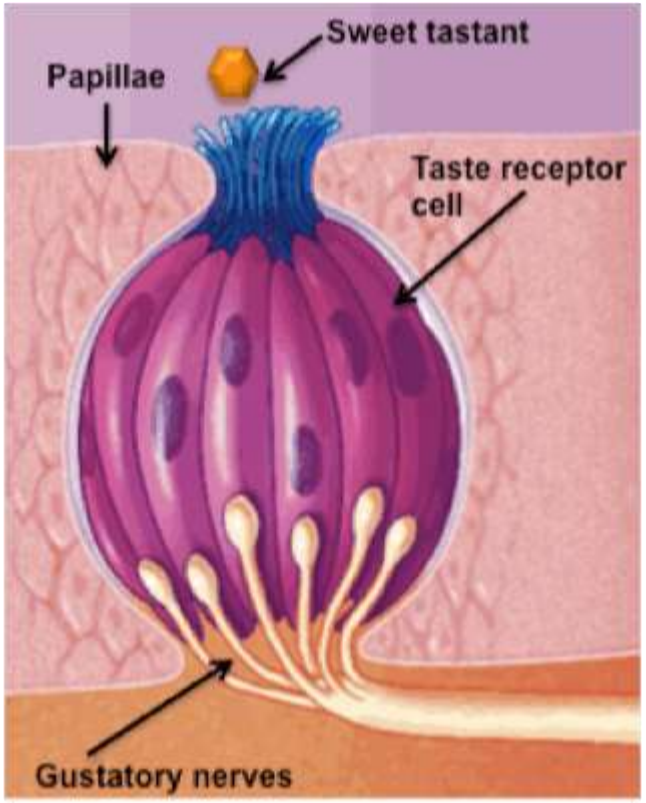
Monosaccharides	Oligosaccharides	Polysaccharides
They consist of single saccharide unit.	They are composed of 2 to 10 saccharide units.	They are composed of more than 10 saccharide units.
They are simplest carbohydrates; therefore, they cannot be further hydrolyzed.	They have less complex structure, so upon hydrolysis they yield at least 2 and maximum 10 monosaccharides.	They have highly complex structure, so upon hydrolysis they yield at least 11 monosaccharides.
They are highly soluble in water.	They are less soluble in water.	They are generally insoluble in water.
They are sweetest among all carbohydrates.	They are less sweet in taste.	They are tasteless.

Why polysaccharides are Tasteless?

On our tongue, we have **taste receptors**.

Our **sweet-receptors** bind to specific types of molecules, namely **monosaccharides** and **disaccharides**.

Polysaccharides are **tasteless** because they do not readily bind to the sweet-receptors on our tongue, as the other smaller molecules do!

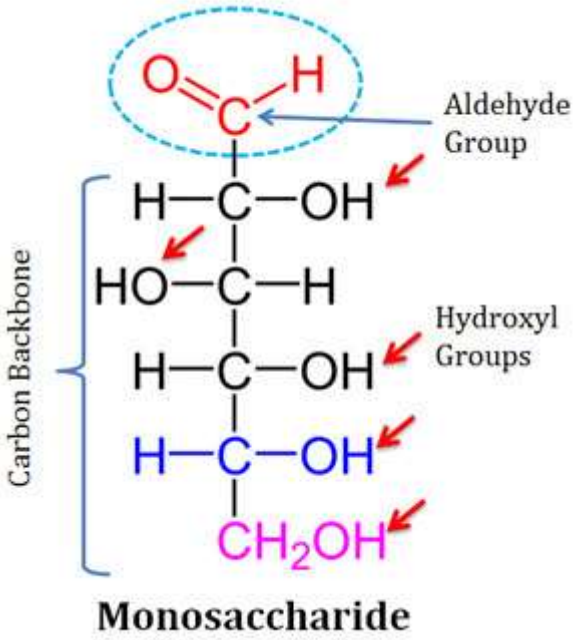


Why polysaccharides are insoluble in water?

Sugars are soluble in water because they contain polar parts such as -OH groups.

Hydroxyl groups (-OH) are polar and therefore hydrophilic (water liking).

Monosaccharides and disaccharides have many free OH groups, and are small enough to dissolve easily in water.

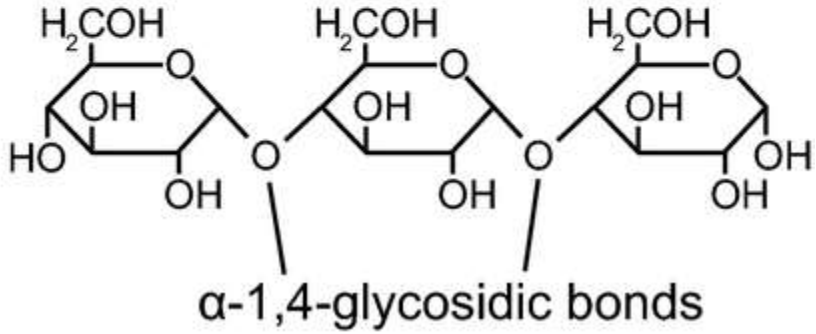


Why polysaccharides are insoluble in water?

Polysaccharides such as starch (amylose) coil into spiral-like helices and their **OH groups** are **tucked** (folded) inside **coils** and are prevented from interacting with water. Thus making polysaccharides **insoluble** in water.

amylose

O = single glucose unit



2.3.2 Monosaccharides

Monosaccharides are true carbohydrates which are either polyhydroxy aldehydes or polyhydroxy ketones. The range of number of carbons in monosaccharides is 3 to 7. All the carbon atoms in a monosaccharide except one, have a hydroxyl group (-OH) while the remaining carbon atom is either the part of aldehyde or ketone. The general formula for the representation of monosaccharides is $C_nH_{2n}O_n$, where, n is the number of carbon atoms in monosaccharides.

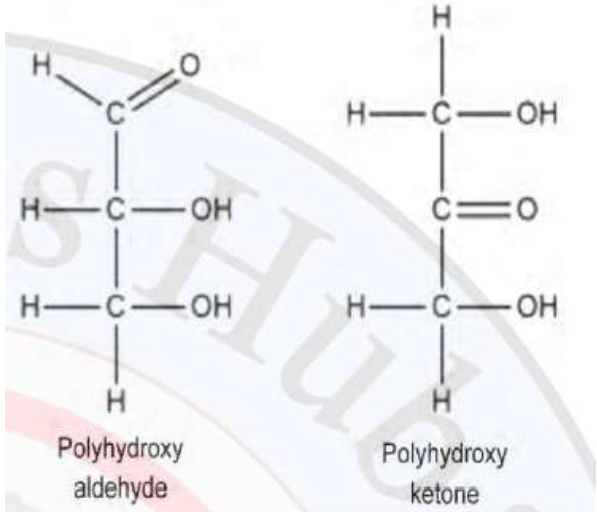


Fig: 2.9: Chemical nature of carbohydrates

Classification of monosaccharides

Classification of monosaccharides is based upon functional group and number of carbon atoms. On the basis of functional group, the monosaccharides containing aldehyde are called **aldoses** while those containing ketone are called **ketoses**. On the other hand monosaccharides are classified into five groups based upon number of carbon atoms i.e., **trioses** (3C), **tetroses** (4C), **pentoses** (5C), **hexoses** (6C) and **heptoses** (7C).

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Table: 2.3: Examples and functions of monosaccharides

Class	Formula	Aldoses	Ketoses	Function
Trioses (3C)	$C_3H_6O_3$	Glyceraldehyde	Dihydroxy acetone	Intermediates in photosynthesis and cellular respiration.
Tetroses (4C)	$C_4H_8O_4$	Erythrose	Erythrulose	Intermediates in bacterial photosynthesis.
Pentoses (5C)	$C_5H_{10}O_5$	Ribose, Deoxyribose ($C_5H_{10}O_4$)	Ribulose	Ribose and deoxyribose are components of RNA and DNA respectively. Ribulose is an intermediates in photosynthesis.
Hexoses (6C)	$C_6H_{12}O_6$	Glucose, Galactose	Fructose	Glucose is respiratory fuel (initial substrate) Fructose is an intermediate in respiration. Galactose is the component of milk sugar.
Heptoses (7C)	$C_7H_{14}O_7$	Glucoheptose	Sedoheptulose	Intermediates in photosynthesis.

Chemical structures of monosaccharides

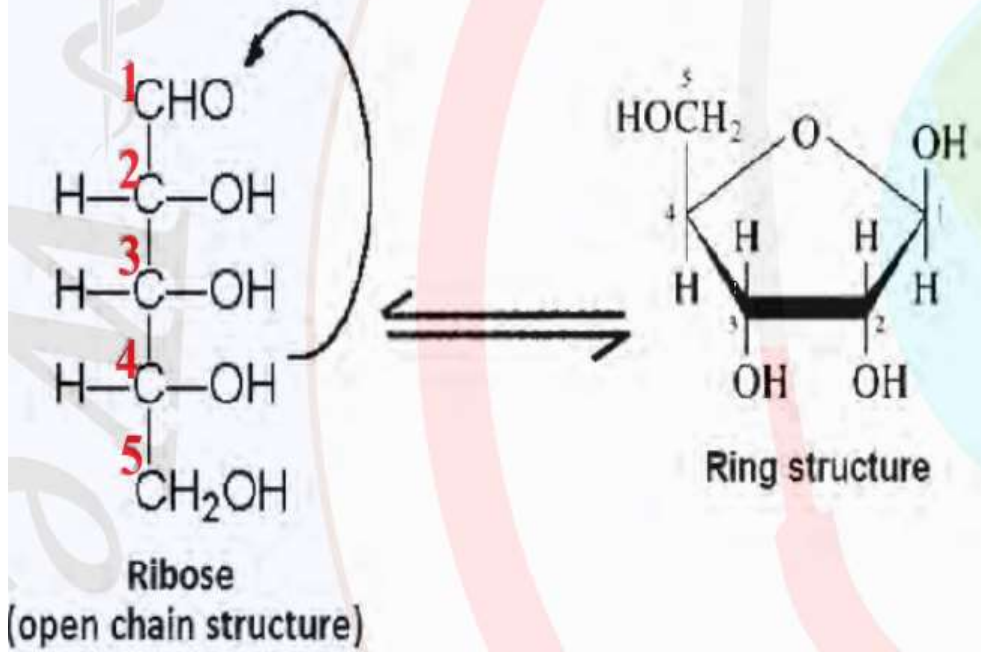

Fig: 2.10: Conversion of open chain into ring chain

Monosaccharides are usually found in open chain structure in crystalline form but when they are dissolved in water most of them (pentoses and hexoses) are converted into ring chain structure.

Let us understand it by taking ribose ($C_5H_{10}O_5$) as an example. It can exist in open chain structure in dried form but it exists in ring structure in aqueous medium. When it is dissolved in water, the oxygen atom from aldehyde group reacts with second last carbon i.e., C4 in case of ribose. In this way oxygen atom forms a link between C1 and C4 while the OH group of C4 is shifted to C1. After this modification ring structure of ribose is formed.

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α (Alpha) sugar and beta (β) sugar

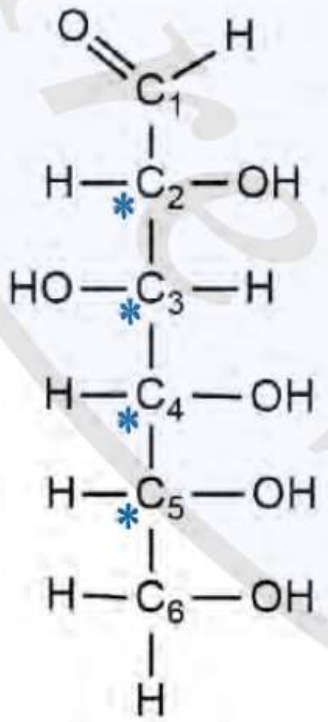

Fig: 2.11: Glucose open chain structure

Each pentose or hexose molecule in ring structure exists in either α or β form depending upon the position of –H and –OH group on C-1. If –OH group is found downward on C-1 then it is called **α sugar** and if –OH is present upward on C-1 then it is known as **β sugar** as shown in the fig: 2.12.

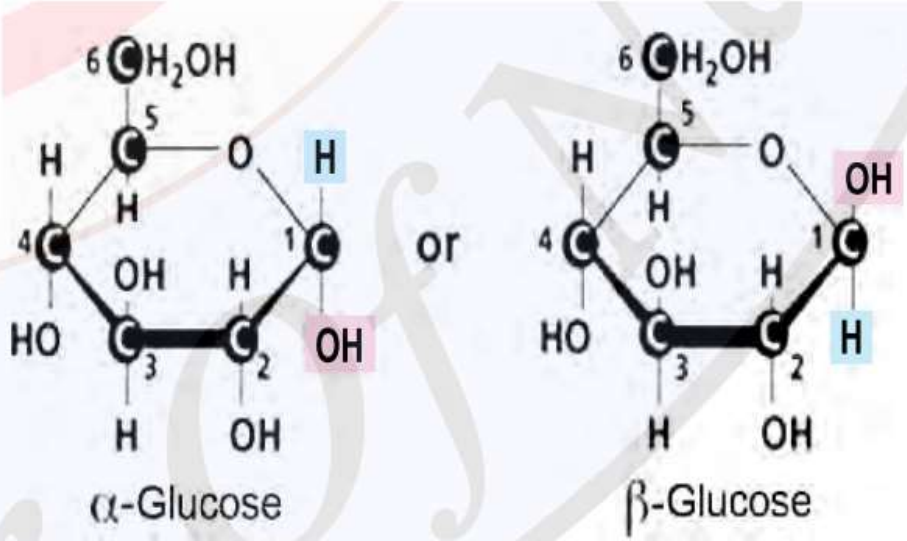

Fig: 2.12: *α* and *β* isomers of glucose

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Stereoisomerism in Glucose

Stereoisomers are molecules that have the same molecular formula and differ only in how atoms are arranged in 3D space.

Stereoisomers

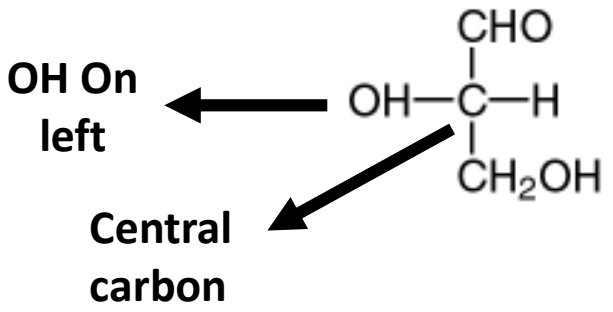
Some isomers differ only in the way in which the atoms are arranged in 3-D space, that is, the atoms are bonded to each other in the same way, but are arranged differently in 3-D space.

Therefore, sugars can exist as pairs of stereoisomers which are mirror images of one another.

The center C-atom of glycerose is called an asymmetric C-atom because it can be rearranged in space to produce two different structures.

An L-isomer has the OH on the left of the center carbon, and the D-isomer has the OH on the right of the center carbon.

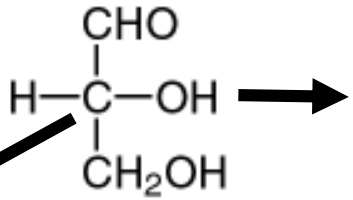
L-Glycerose



OH On left

Central carbon

D-Glycerose

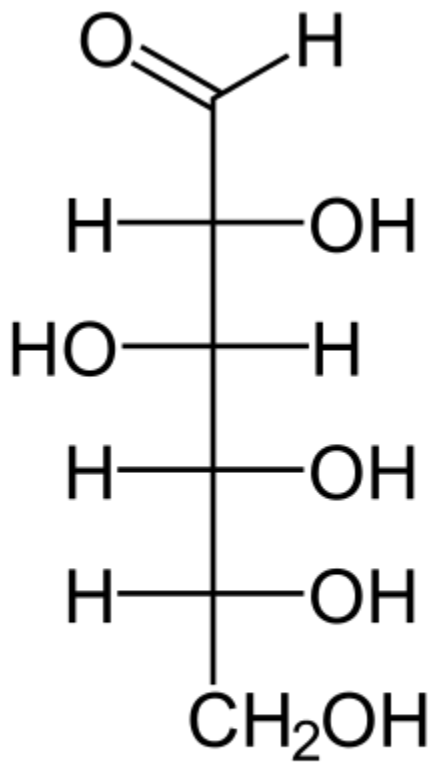


OH On Right

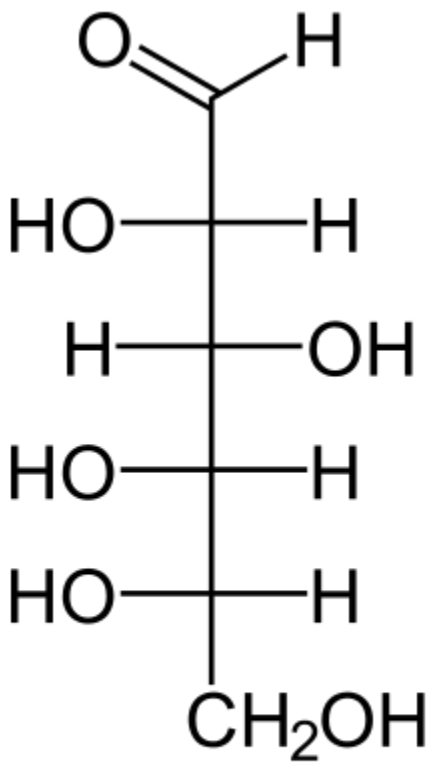
Central carbon

Differentiate between D-Glucose and L-Glucose

If the OH on the bottom of second last carbon (chiral carbon) points to the right, it is referred to as D- glucose)



D-Glucose



L-Glucose

If the OH on the bottom of second last carbon (chiral carbon) points to the left, it is referred to as L- glucose)

D and L isomers are stereoisomers but are non-superimposable.

Enantiomer (enan-tio-mer)

What is an Enantiomer? →

Enantiomers are a pair of molecules that exist in two forms that are mirror images of one another but cannot be superimposed (laid over) one upon the other.

Each of a pair of molecules that are mirror images of each other

•Enantiomers are example of a type of stereoisomers.

•Compounds that occur in these pairs are called "chiral".

•"Chiral" comes from the Greek word for "hand".

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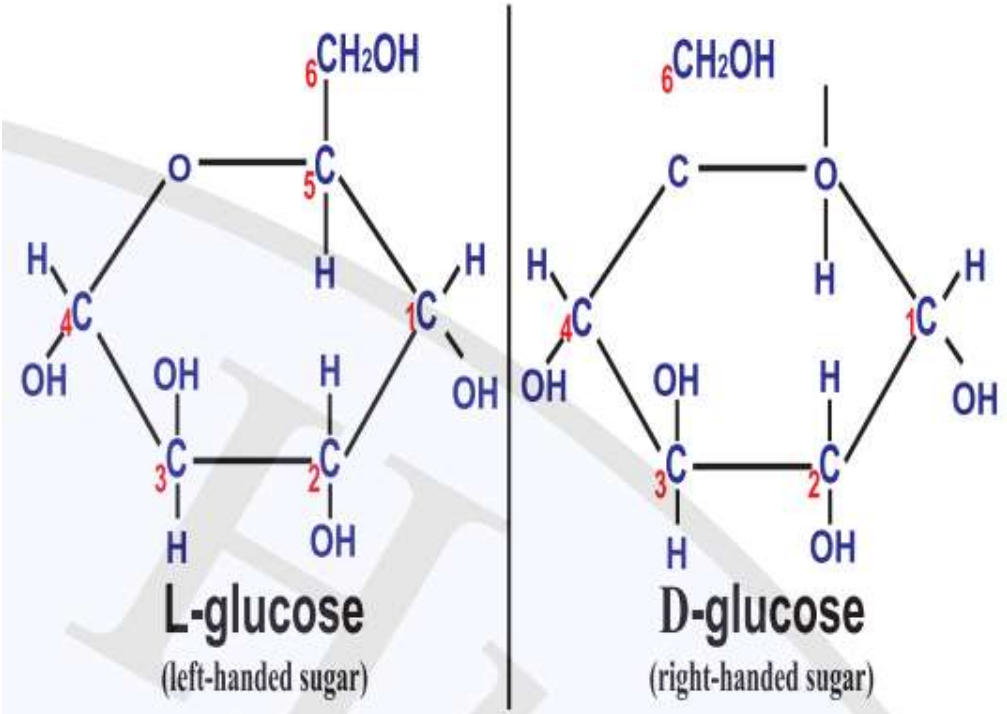


Fig: 2.13: An example of enantiomers

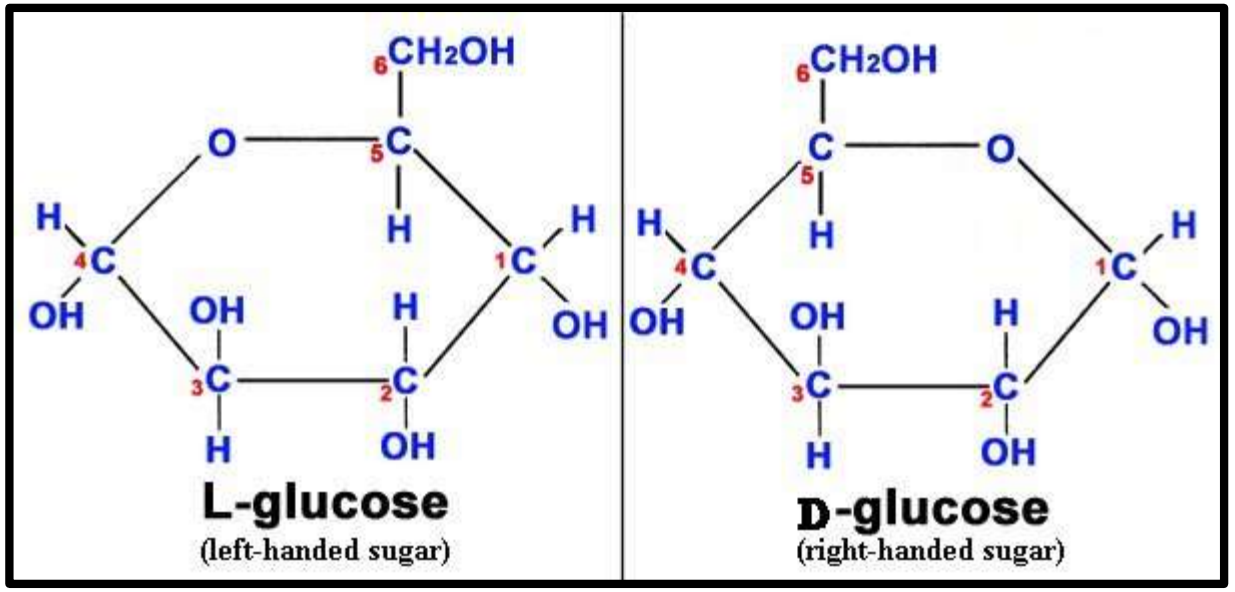
When a sugar is provided in ring form (how do you tell if it is L or D?

I know L or D comes from the last chiral carbon (An asymmetric carbon atom) . This is easy to determine in Fischer projection.

Fischer projection, method of representing the three-dimensional structures of molecules on a page, devised by Emil Fischer.

For the Fischer projection:

If the last chiral center points to YOUR RIGHT, it's D.
If the last chiral
center points to YOUR LEFT, it's L.



2.3.3 Oligosaccharides

This group consists of derivatives of monosaccharides. Those carbohydrates which upon hydrolysis yield 2 to 10 saccharide units are called oligosaccharides. On the basis of number of saccharide units, the oligosaccharides are classified into **disaccharides**, **trisaccharides, tetrasaccharides** and so on. The most common among these are disaccharides.

Disaccharides

Two monosaccharides combine to form a disaccharide. It is a kind of oligosaccharides. Disaccharides are less sweet in taste and less soluble in water. These can be hydrolyzed to give monosaccharides. Examples are: maltose, lactose, sucrose. The general formula of disaccharide is: $C_{12} H_{22} O_{11}$.

C 6 H 12 O 6 + C 6 H 12 O 6 → C 12 H 22 O 11+ H 2 O

Examples of disaccharides

- $C_6H_{12}O_6 + C_6H_{12}O_6 \rightarrow C_{12}H_{22}O_{11} + H_2O$
- Glucose + Glucose → Maltose + water
- Glucose + Fructose → Sucrose + water
- Glucose + Galactose → Lactose + water

SOURCE OF DISACCHARIDES

- **Sucrose: glucose + fructose; table sugar**
- **Lactose: glucose + galactose; milk sugar**
- **Maltose: glucose + glucose; product of starch digestion**

Dextrin

- **– Carbohydrates containing 3 to 10**

sugar units are referred to Dextrins.

- **– Glucose + glucose + glucose = Maltotriose**
- **– Glucose + fructose + fructose = Kestose**

The general formula for monosaccharaides is $C_nH_{2n}O_n$

"n" stands for number

This formula only applies to simple sugars, which are equal parts of carbon and water.

For example Glucose
This monosaccharide
has a chemical formula $C_6H_{12}O_6$.

Complex sugars, do not have this general formula.

For example a disaccharide has a chemical formula
C 12 H 22 O 11.
where Carbon number is not equal to water molecules.

Complex carbohydrates have general formula $C_x(H_2O)_y$, where x and y are variable numbers.

Here x is not equal to y.
Means C number is not equal to H_2O.

For example a disaccharide has a chemical formula
$C_{12}H_{22}O_{11}$.
where Carbon number is not equal to water molecules.

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Glycosidic bond

In this reaction, the –OH group at C-1 of glucose reacts with the –OH group at C-2 of fructose, liberating a water molecule forming **α-1,2-glycosidic linkage**.

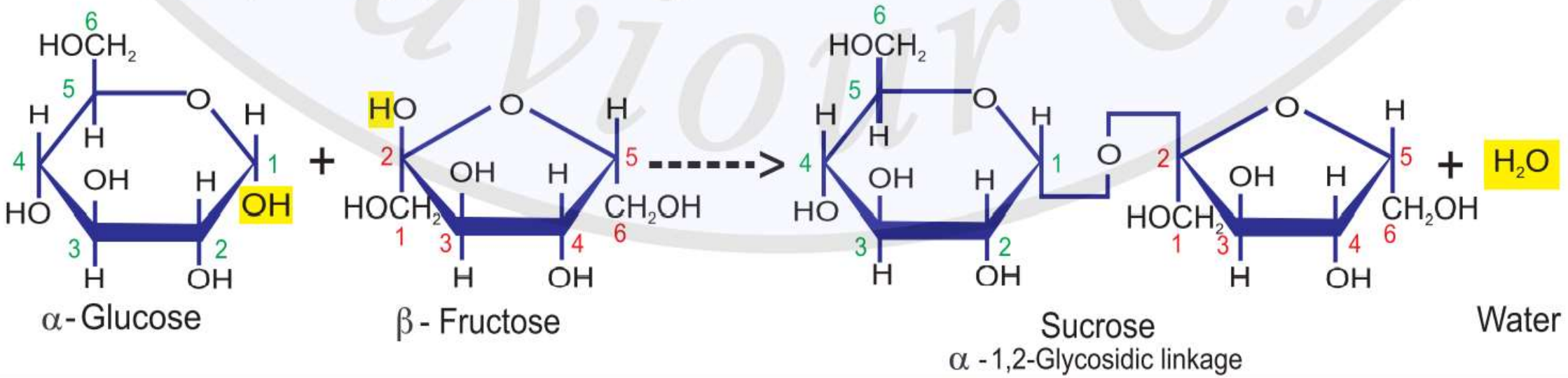


Fig: 2.14: Formation of sucrose

POLYSACCHARIDES

(Gr: Poly = many, L saccharum = sugar)

Polysaccharides are macromolecules which are formed by condensation of few hundred to a few thousand monosaccharides.

Polysaccharides, have a general formula of $C_x(H_2O)_y$, where x and y are variable.

Polysaccharides are tasteless and are insoluble in water.

Classification of polysaccharides

These are divided into three min groups
– (1) GLYCOGEN
– (2) STARCH
– (3) CELLULOSE

(1) GLYCOGEN

It is storage polysaccharide of animal cells.

Glycogen is also known as animal starch.

Glycogen is generally stored in liver and muscles of animals.

Various samples of glycogen have been measured at 10,000 - 50,000 units of glucose.

STARCH

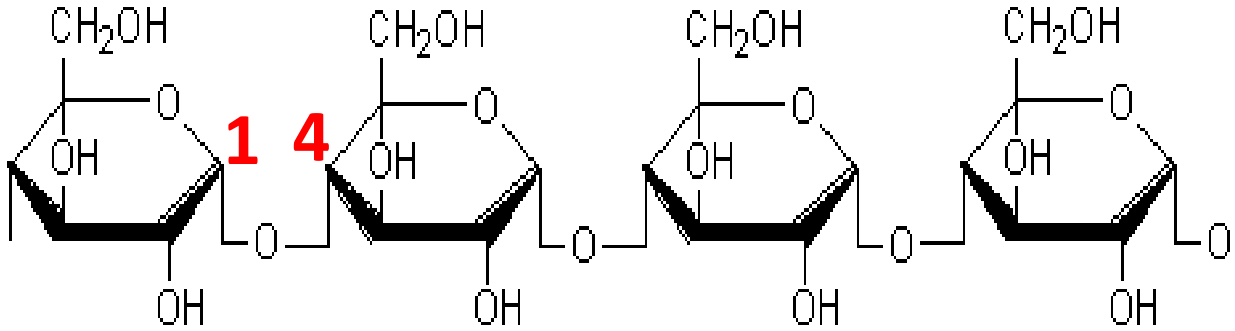
Starches are polymers of glucose and are storage polysaccharides of plants.

There are two forms of starch:

- AMYLOSE
- AMYLOPECTIN

Amylose: consists of linear, unbranched chains of several hundred glucose units (5,00—2,000 units).

Amylose structure

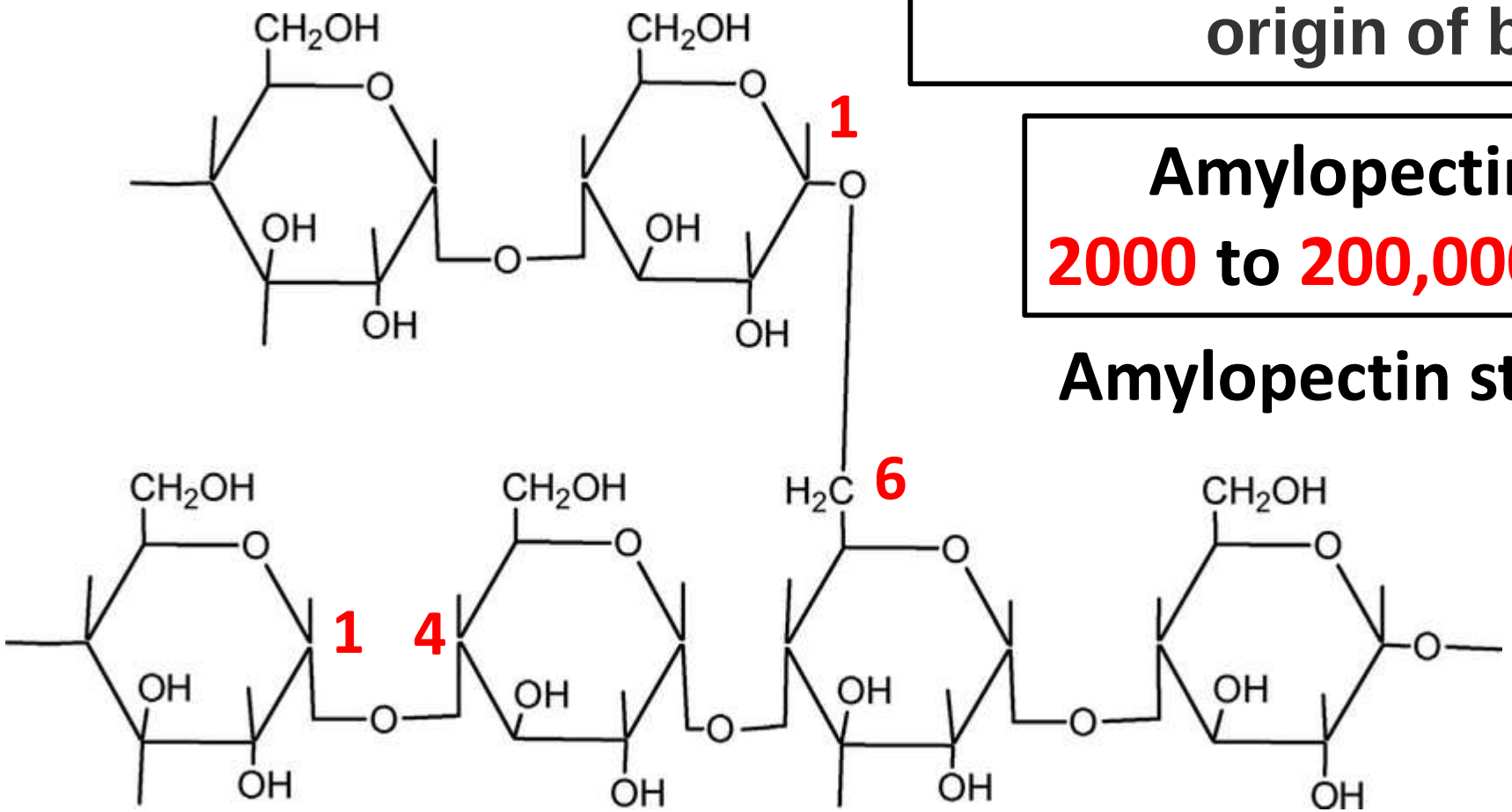


(1→4) glycosidic bonds

Amylopectin:
differs from amylose in being highly branched.

There are 1→4 glycosidic bonds in linear chains, while 1→6 glycosidic bonds are present at the origin of branches.

Amylopectin formed of 2000 to 200,000 glucose units.

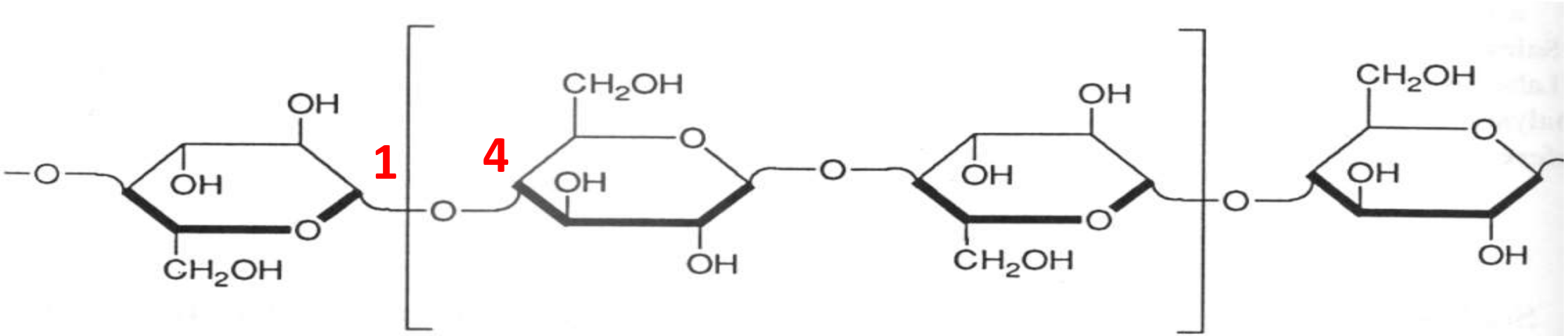


Amylopectin structure

CELLULOSE

Cellulose is the most important **structural polysaccharide** of the cell wall of plants.

There are no side chains in cellulose.
Cellulose can have **2,000 - 14,000** glucose units.



Section of cellulose

Cellulose is a linear polymer in which glucose units are joined by **1-4** glycosidic bonds.